Military Orthopaedics

Zones of hemorrhage: defining vascular injury in military patients with complex pelvic fractures — a consensus panel review

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ABSTRACT

Background

Junctional extremity and noncompressible hemorrhage are difficult challenges facing the prehospital provider on the battlefield. The subset of casualties with pelvic or truncal vascular injury represents a challenge in hemorrhage control.

Methods

The Armed Forces Medical Examiner (AFME) System was queried for nonsurvivors with significant vascular injuries and an associated pelvic fracture. A panel of military experts in prehospital care, vascular surgery, and orthopaedic surgery reviewed all records. Zones of hemorrhage were categorized as Zone I, area of injury allowing tourniquet use; Zone II, area of injury compressible but not allowing tourniquet use; or Zone III, noncompressible. Currently available and emerging technologies for hemorrhage control were reviewed and potential applicability of each modality determined.

Results

An AFME database search yielded 49 nonsurvivors with pelvic fractures and associated vascular injuries. Zone I hemorrhage injuries were present in 21% of patients, Zone II in 19%, and Zone III in 60%, accounting for 115 total injuries. Thirty percent (n = 15) of patients had uncontrollable hemorrhage, 39% (n = 19) had hemorrhage potentially controllable by the battlefield prehospital provider, and 30% (n = 15) were deemed compressible with emerging technologies not available on the battlefield. Sixty-one percent (n = 30) had vascular injuries that were noncompressible using battlefield-available methods.

Conclusions

The majority of battlefield vascular injuries in nonsurvivors were not controllable using technology available to the prehospital responder. Classifying battlefield hemorrhage into zones of hemorrhage may allow us to focus future research and intervention development.

Key Words

zones of hemorrhage, noncompressible hemorrhage, battlefield

INTRODUCTION

Hemorrhage from extremity injuries has been intensely studied as it historically has been the leading cause of preventable battlefield deaths.[1] Studies from recent conflicts have examined prehospital tourniquet use for extremity exsanguination in patients who present to a forward surgical facility.[2,3••] Because of ongoing battlefield research, we have seen a change over the past decade in battlefield management of limb exsanguination using tourniquets; compressible extremity hemorrhage is no longer the most common cause of preventable battlefield deaths due to hemorrhage.[4] Noncompressible hemorrhage now represents the most common cause of battlefield death due to hemorrhage, the only treatment for which is rapid evacuation from the battlefield to surgical care. In an era when the majority of battlefield deaths are secondary to blasts and explosive projectiles rather than gunshot wounds, the subset of wounded warriors with junctional and truncal or pelvic hemorrhage now represents the most common cause of potentially preventable deaths due to hemorrhage.[5] Holcomb *et al.*[6] found that 15% of battlefield deaths, most secondary to penetrating trauma, were potentially survivable. Of those, hemorrhage represented 81% of potentially survivable injuries, while noncompressible hemorrhage represented 51%.[6] Similar studies have identified noncompressible torso hemorrhage as the most common cause of potentially survivable deaths (49-80%).[5,7]

To our knowledge prehospital hemorrhage data on battlefield casualties, specifically on truncal and pelvic vascular injuries, have not been described. Nor is there a widely adopted simple classification of zones of hemorrhage to facilitate prehospital documentation and further research.[1] Pelvic trauma predisposes the patient to major vascular

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injuries with resulting hemodynamic instability, to include extra-pelvic trauma. Multiple civilian trauma studies demonstrate rates of associated vascular injury with unstable pelvic fractures at 80%, with mortality rates approaching 40%.[8–11] Data from recent battlefield conflicts identified associated large vessel injury in 44% of casualties with pelvic fractures and mortality rates of 90% in the prehospital setting before reaching surgical care.[12] A previously published cohort of nonsurvivors with pelvic injuries revealed a large number for service members with associated vascular injuries.[13] The purpose of this study was to examine nonsurvivors and define the location and frequency of concomitant vascular injuries in military patients with pelvic fractures. By assigning these vascular injuries into Zones, we sought to define possible interventions to improve survival in this nearly universally fatal injury.

MATERIALS AND METHODS

A retrospective analysis was performed after approval by our institutional review board.

All U.S. service members whose remains are recovered are transported to The Armed Forces Medical Examiner (AFME) in Dover, DE where a complete forensic examination is performed. The AFME database was queried for service members who were either killed in action or died of wounds with an ICD-9 documented pelvic fracture in 2008. The year 2008 was chosen because this particular year had the most complete documentation to include autopsy reports and electronic imaging (CT scans and radiographs). These data were abstracted to create the STReC pelvis database.[13] The STReC pelvis database was then reviewed for associated vascular injury or amputation. In addition to autopsy reports and imaging studies, documentation consisted of mechanism of injury, blunt versus penetrating injury, and prehospital and tertiary interventions. Pelvic fractures were classified according to the Tile classification.

A multidisciplinary consensus panel of military experts in the fields of prehospital care, vascular surgery, and orthopaedic trauma surgery was assembled to review these records. The consensus panel formulated a categorization scheme into zones of hemorrhage based on compressibility. Zone I was defined as an extremity vascular injury or distal amputation that allowed for manual compression and tourniquet use. Zone II was defined as a junctional vascular injury or proximal extremity amputation that allowed for manual compression but was too proximal for tourniquet use. Zone III was defined as thoracic, abdominal, pelvic vascular injury that is noncompressible and for which there is currently no effective prehospital intervention (Figure 1).

The consensus panel then reviewed all current modes of hemorrhage control available to the prehospital provider as described in Table 1. The panel then discussed emerging technologies as well as those not available on the battlefield and formulated a list of those potentially usable on the battlefield by a prehospital responder. These devices consisted of external iliofemoral compression devices, abdominal aortic compression device, and intravascular balloon occlusion catheter, among others. Interventions were then assigned to each zone of hemorrhage as in Table 1.

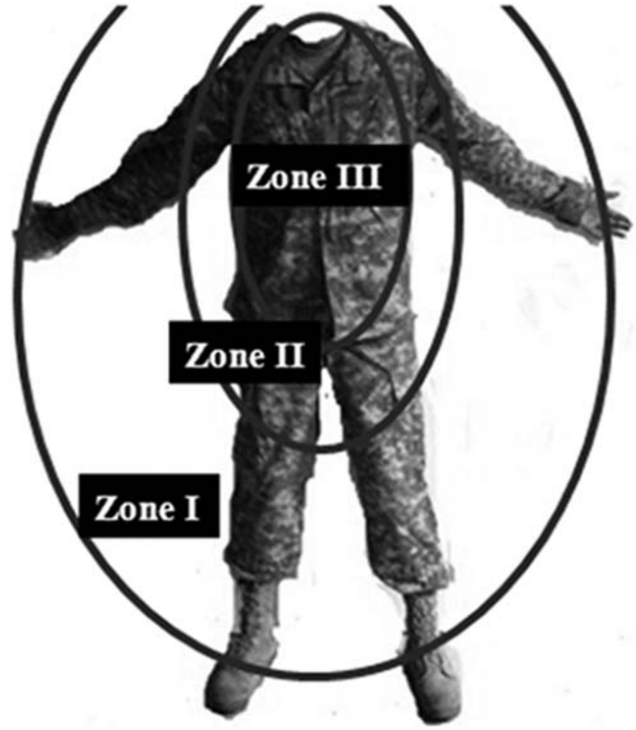

FIGURE 1. Zones of hemorrhage.

Next, the multidisciplinary consensus panel reviewed each patient record summary and identified the zones of hemorrhage and the associated hemorrhage control modality. Potential applicability of each modality was based on the most severe zone of injury for each patient by way of retrospective triage. In the cases of iliac vessel injury, the Tile classification of pelvic fracture determined applicability of a pelvic binder or military anti-shock trouser (MAST). In cases considered for a balloon occlusion catheter and external aortic compressive device, only infrarenal aortic hemorrhage was considered. Records were reviewed

TABLE 1. Classification of zone of hemorrhage with associated interventions

Zone of hemorrhage	Compressibility	Intervention
I	Compressible, amenable to tourniquet	Manual pressure, CAT, topicals, CRoC, external aortic compression, balloon occlusion
II	Compressible only	Manual pressure, topicals, CRoC, external aortic compression, balloon occlusion
III	Noncompressible	CRoC, pelvic binder, MAST, external aortic compression, balloon occlusion

CAT, combat applied tourniquet; CRoC, combat ready clamp; MAST, military anti-shock trousers.

and discussed until a consensus opinion on each case was achieved.

It must be emphasized that the scope of this study was not to evaluate or discuss tertiary management of these patients, to include fluid resuscitation and administration of anti-thrombolytics.

Description of Devices and Justification for Inclusion in this Study

The following compressive devices were analyzed by the roundtable members: manual pressure; combat application tourniquet (C-A-T, Composite Resources, Rock Hill, SC); pelvic binder or sheet; military anti-shock trousers (MAST, David Clark Inc, Worcester, MA); femoral occlusion devices, such as combat ready clamp (CRoC Combat Medical Systems Fayetteville NC); external aortic compression devices, such as an abdominal tourniquet or aortic clamp, and intravascular balloon occlusion. Manual pressure, CAT, pelvic binder, and MAST are available to the combat medic; research on these devices is abundant.

The CRoC has been shown to stop arterial flow when applied to the common iliac and femoral arteries in the Wake Forest University human cadaver hemostasis model and has recently been FDA-approved as a junctional tourniquet.[3]

The external aortic compression device is a compressive metal spring cylinder placed just left of the umbilicus and held in place with a circumferential strap. It maintains 30 kg of pressure over the abdominal wall on the aorta and has been shown to stop femoral pulses.[14] Also, a pneumatic abdominal tourniquet device from the Medical College of Georgia has demonstrated compression of the abdominal aorta in animal studies.[15]

Balloon occlusion has been used intraoperatively for intravascular occlusion of uncontrollable hemorrhage associated with pelvic fractures.[16] Recently, it has been shown to decrease the mortality rate in uncontrolled hemorrhage after pelvic fractures. Researchers blindly inserted an intra-aortic balloon catheter in hemodynamically unstable patients with pelvic fractures. Blind insertion was successful in all cases and verified by angiography. Access was through the femoral artery with resulting occlusion at the aortic bifurcation. Mean occlusion time was 70 minutes until intravascular embolization or definitive surgical ligation could be performed.[12]

RESULTS

The STReC pelvis database yielded 104 subjects with battlefield pelvic fractures in 2008; this number was reduced to 93 after records without imaging confirming pelvic fracture were excluded. These records were then reviewed for associated vascular injury or amputation, resulting in 59 subjects. Ten of these service-members had devastating nonsurvivable head trauma (brain pulpification, decapitation) and were excluded after case review.

Forty-nine service members met the inclusion criteria for pelvic fractures and major vascular injuries. All subjects were male, and all other demographics to include age, race, and rank were deidentified.

Mechanism of Injury

Mechanism of injury was predominantly blast, as seen in Table 2. Improvised explosive device (IED) blasts accounted for 34 deaths (69%), 10 of which were dismounted, or extravehicular. The remainder of mechanisms included: six blasts (12%), four gun-shot wounds (GSW), three nonhostile motor vehicle collisions, one anti-tank mine, and one explosively formed penetrator. A blast accounted for 86% of casualties. Most injuries for all mechanisms were noncompressible, with the exception of the death associated with an anti-tank mine.

Injuries

Injury patterns were as follows: three patients had blunt injuries, 15 had penetrating, and 31 had both (63%). Zone I hemorrhage injuries were present in 24 subjects (21%), Zone II in 22 (19%), and Zone III in 69 (60%), accounting for 115 total injuries as depicted in Figure 2. Two patients had both Zone II and Zone III injuries, while 21 patients (42%) had multiple Zone III injuries. Of those with Zone III hemorrhage, 40% had an iliac vessel injury and 29% had an aortic injury (Table 3).

Potentially Compressible Hemorrhage

A total of 61% (n = 30) subjects had vascular injuries that were noncompressible using currently available battlefield methods. Of these, 15 subjects had uncontrollable hemorrhage by any means (Table 3) and 15 had potentially compressible hemorrhage, with emerging technologies not available on the battlefield. Thirty-nine percent (n = 19) had

TABLE 2. Mechanisms of injury

Mechanism	Number (% total)	Potentially compressible N (% mechanism)	Noncompressible N (%)
All explosions	42 (86)	18 (43)	24 (57)
IED	34 (69)	14 (41)	20 (59)
Blast	6 (12)	3 (50)	3 (50)
Anti-tank mine	1 (2)	1 (100)	0 (0)
EFP	1 (2)	0 (0)	1 (100)
Gunshot wound	4 (8)	1 (25)	3 (75)
MVC without IED	3 (6)	0 (0)	3 (100)
Total	49	19	30

EFP, explosively formed projectile; IED, improvised explosive device; MVC, motor vehicle collision.

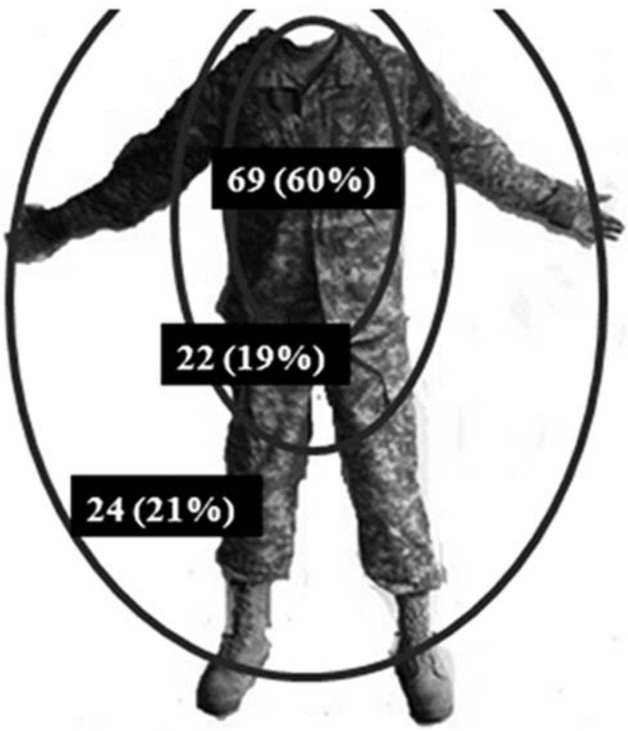

FIGURE 2. Injuries by zone of hemorrhage.

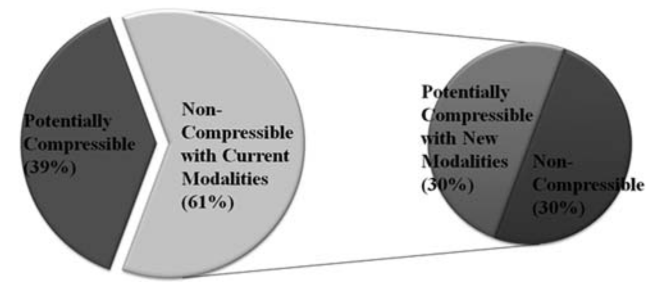

FIGURE 3. Compressible versus noncompressible Injuries.

hemorrhage potentially controllable with current methods, as represented in Figure 3.

DISCUSSION

Junctional and truncal or pelvic hemorrhages now represent the most common cause of preventable battlefield death due to hemorrhage, however prehospital care data are lacking in current conflicts.[2,3••] There were 93 casualties with pelvic fractures in 2008, 63% of these had an associated vascular injury. We found that most of these vascular injuries were noncompressible, half of which had potentially compressible hemorrhage using a modality not available on the battlefield, specifically an intravascular balloon occlusive device, the combat ready clamp, or an external aortic compressive device.

The mortality rate for a service member sustaining a combat-related pelvic fracture is 90.1% (91/101) with a survival rate of 9.9%.[17••] Civilian literature cites the incidence of extrapelvic hemorrhage with pelvic fracture as 31%; with chest 15%, abdominal 32%, and extremity 40%.[9] We found an overall incidence of truncal or pelvic vascular injury with pelvic fracture to be 63%, which is not unexpected because of the blast mechanism of injury. This makes further comparison to civilian literature difficult, as 80-90% of civilian deaths are secondary to a fall or motor vehicle crash, resulting in a blunt mechanism.[18] In battlefield settings with multiple casualties, identifying those with pelvic fractures and hemorrhage may enable allocation of medical care and resources to those with a higher likelihood of survival.

Explosions have increasingly become the predominant mechanism of injury as evidenced in our study representing 84% of injuries, compared with Holcomb's[5] 55% of OIF or OEF deaths in 2004. In our data, we found that over half of all injuries were secondary to mounted IED blasts, resulting in both blunt and penetrating trauma.

TABLE 3. Vascular injury by zone of hemorrhage

	Injuries	Percent by zone (%)	Percent total (%)
Zone I	24		20.87
Brachial	1	4.17	0.87
Basilic vein	1	4.17	0.87
Distal upper extremity	6	25.00	5.22
Distal lower extremity	16	66.67	13.91
Zone II	22		19.13
Femoral	3	13.64	2.61
Carotid	1	4.55	0.87
Proximal upper extremity	6	27.27	5.22
Proximal lower extremity	12	54.55	10.43
Zone III	69		60
Aorta	20	28.99	17.39
Atrium/ventricle	8	11.59	6.96
Pulmonary	4	5.80	3.48
Renal	2	2.90	1.74
Vena cava	6	8.70	5.22
Iliac	28	40.58	24.35
Pelvic floor	1	1.45	0.87
Total	115		

Thirty percent of patients (n = 15) had uncontrollable hemorrhage, 39% (n = 19) had hemorrhage potentially controllable by the battlefield prehospital provider, and 30.5% (n = 15) were deemed compressible with emerging technologies not available on the battlefield. We found that 61% (n = 30) of casualties had vascular injuries that are noncompressible using battlefield-available methods. Of these casualties, 21 (71%) had multiple injuries, 17 of them being an additional Zone III injury. The casualties with noncompressible hemorrhage included 15 patients with uncontrollable hemorrhage by any means, and 15 patients with potentially compressible hemorrhage using a modality not available on the battlefield, such as an intravascular balloon occlusive device, the combat ready clamp, or an external aortic compressive device.

Of the 39% (n = 19) with potentially controllable hemorrhage, 84% (n = 16) had multiple vascular injuries. Thirty-seven percent (n = 7) had Zone III injuries, 52% (n = 10) had Zone II injuries, and 31% (n = 6) had Zone I injuries, accounting for 40 injuries in these 19 fatalities. All instances of potentially controllable Zone III hemorrhage were associated with an unstable pelvic fracture that could have benefitted from a pelvic binder or MAST, which accounted for a minority of all iliac vessel injuries.

In our cohort of 49 casualties, there were a total of 115 vascular injuries, 69 of these being in Zone III. Of those, 40% had iliac vessel injury and 29% had an aortic injury. These are areas where future research and development should focus. Interventions for controlling Zone I hemorrhage, including tourniquet and manual pressure have proven effective on the battlefield. Zone II hemorrhage control currently includes manual pressure and hemostatics. On the battlefield today, the only intervention available for Zone III hemorrhage is rapid evacuation to surgical care. Given the delay in evacuation inherent in military operations, to include weather, enemy forces, low light, and ongoing combat operations, survival of these patients will require intervention in the prehospital setting. Optimal interventions in the prehospital setting for these severely injured patients have not yet been defined. Their survival will likely depend on multiple surgical interventions that include fluid and blood product resuscitation and mechanical methods of hemorrhage control such as the novel devices mentioned above.

Although frequent retrospective analysis of battlefield deaths is needed, autopsy data alone are not sufficient to accurately characterize these injuries or predict which devices would most precisely control hemorrhage; prehospital data are needed. Designating battlefield vascular injuries into zones of hemorrhage and documenting prehospital interventions may provide a framework for further investigation.

Many of these patients had prehospital intervention, which was documented by the AFME at time of autopsy. However, the actual number of prehospital interventions cannot be known, especially in the cases of applying manual pressure and removal of an intervention, such as removal of a tourniquet or pelvic binder to render specialized care. Therefore, the number of those with potentially survivable hemorrhage might actually be less than that reported in our study. Also, our analysis focused on a specific population, combat casualties with pelvic fractures and peripelvic hemorrhage, while this may limit generalizability to the combat casualty population, the proposed zones of hemorrhage can be applied to any patient with vascular injury regardless of associated injuries.

CONCLUSION

In summary, we propose a new classification system, zones of hemorrhage, based on hemorrhage compressibility. Rates of junctional and truncal or pelvic hemorrhage are unclear, as there is no adopted categorization or coding scheme. Assigning zones of hemorrhage may allow us to better grasp the rates of these fatal injuries and then focus future research and product development. As stated previously, the survival rate of service members with a combat-related pelvic fracture is less than 10%. A rapid means of identification of injury severity using our proposed scheme also may allow more rapid triage and allocation of resources.

The majority of battlefield vascular injuries in nonsurvivors are not controllable using technology available to the prehospital responder. However, there is a subset of nonsurvivors with noncontrollable hemorrhage that is potentially controllable with new emerging technologies not yet available to the prehospital responder on the battlefield.

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In the current war, from 2001-2010, there is a reported 23% potentially survivable rate. Of these, 20% had a junctional vascular injury as a cause of death, which equates to 258 casualties out of 6450 in the time period described. A truncal tourniquet for prehospital use is the ideal solution; however, there continues to be research gaps and development challenges.

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Service members sustaining a combat-related pelvic fracture have a 9.9% survival rate. Stable Tile A fractures were associated with low energy blunt force trauma (motor vehicle accidents, falls) and a 75% mortality rate. Significant predictors of mortality in unstable fractures include large-vessel injury, anatomic brain injury, cardio-pulmonary injury, and solid organ abdominal injury.

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